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FUMIGATION SCHEDULING

BY

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The art of fumigation has gone so far in advance of the science of fumigation that many fumigators have at times felt that science had nothing of value to offer the practical fumigator. As in every other practical art, a point is finally reached—in this case has long been reached—where further progress is impossible without resorting to more accurate methods.

Foremost of all the problems of fumigation is the securing of accuracy in scheduling an orchard, because both efficiency and economy depend more on this factor than upon any other.

While there may be reason for difference of opinion as to the amount it is proper to use at different times of the year, for different insects, or for trees of different size, there is no difference of opinion possible in regard to the contention that trees alike in all respects should have equal dose. We have records of the work of about forty fumigators and not one was found who did not vary in his judgment in trees of identical size to the extent of at least fifty per cent.

Fumigators very generally recognize the desirability of measuring instead of guessing the size of trees and would no doubt have long ago adopted the practice had there been an acceptable method available, and orchardists, had they fully realized the waste resulting from the present practice and the possibility of more uniform killing of the scale that it is possible to secure, would have insisted upon having the trees measured with as much care as is given to weighing the cyanide.

This Experiment Station urged the measurement of tents from the first and developed all the practical methods of measurement thus far proposed. In the first work on fumigation, Bulletin No. 71, printed in 1887, Mr. Morse used direct measurement of height and

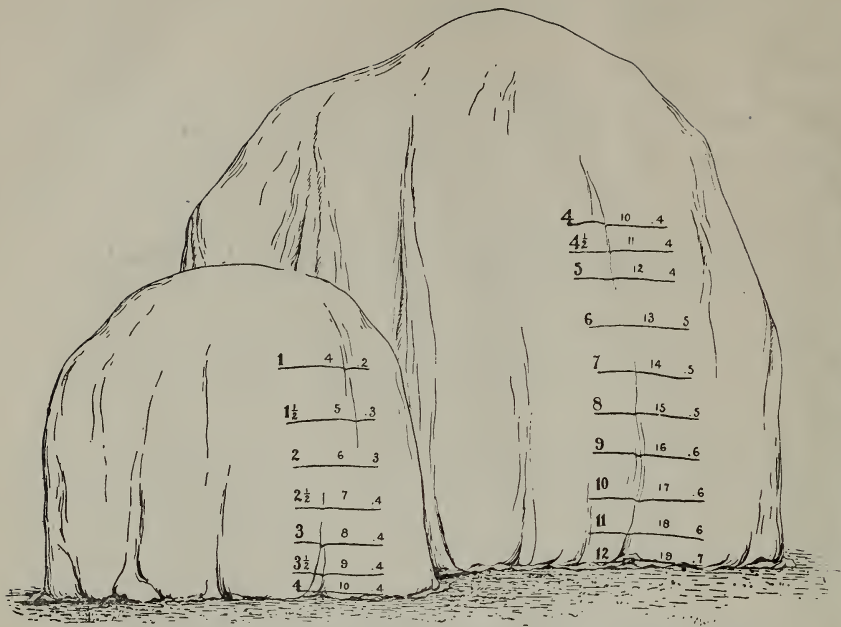


Fig. 1.—One method of marking fumigation tents to indicate dosage.

Fig. 2.—The method of measuring tents employed in securing some of the data discussed in this Bulletin.

diameter. This was done by the use of poles or tapes. His table only gives dosage for tents in which these dimensions are equal. Subsequent writers adopted the same plan, but gave the dosage for trees in which the two dimensions differed.

The first suggested change in the method of obtaining dimensions was in 1894, in Bulletin No. 122, where the idea of first covering the tree with a tent and then measuring the distance over the top and that around near the bottom was suggested and an elaborate table was presented for obtaining the dosage from these measurements. This method was practically used by the writer in the field in 1902 in fumigating for the white fly in the Mantee River section in Florida, where the distance over the tent was read from marks placed on the tent giving the distance down from the middle of the top in feet. A modification of this plan was illustrated in 1904, in Bulletin No. 152 (fig. 1), where the actual dosage was marked on the tent to avoid the inconvenience of calculation. In this same bulletin a rapid method of taking the measurement with lines was also presented (fig. 2) and a diagram furnished whereby the volume could be read at once from such measurements without calculation. No special effort was made by the Station to secure the adoption of any of these methods, and it was not until the work was taken up by the United States Department of Agriculture that finally a portion of the practical fumigators began to apply the method of measurement by marked tents.

The interest having thus been aroused it will be opportune to discuss more fully than has as yet been done, the available methods of measurement and calculation and to describe certain recent improvements in the processes.

THE MEASUREMENTS.

If the tent or tree is calculated as a regular figure the area or volume may be calculated from (1) the height and diameter, (2) the circumference and height, (3) the distance over and height, (4) the distance over and the diameter, or (5) the "circumference and the distance over," that is, from any combination of these four dimensions except circumference and diameter, since the former is only 3.1416 times the latter and gives no clue to the other dimensions. The distance over, however, consists of half the circumference plus twice the height minus the diameter and will therefore give either height or diameter if the other is known. All of these dimensions may be determined optically from the ground except the circumference, and all of them can be measured directly.

Direct measurements.—These may be made in three ways: by pacing, by the use of a pole, or by a tape. Pacing is the least accurate, but decidedly better than the practice of guessing. It is available only for diameter and circumference and therefore must be supplemented by another measurement to give the height. Since the circumference is over three times as long as the diameter it is to a corresponding degree more accurate. The use of a pole is the most practical accurate method of direct measurement for either height or diameter. To obtain the diameter the pole is thrust through the tree from one side until it hits the trunk, giving a semidiameter, or until the end just corresponds with the edge of the foliage when by walking around the tree the amount projecting will enable us to determine the diameter. To obtain the height the pole must be stood upright next to the trunk. The best way is to use two short poles, only one of which need be graduated, and either may be elevated until it reaches the top of the tree.

The tape is not practical except after the tent is on the tree, and only for circumference and distance over. To obtain the circumference requires a trip around the tree. The distance over is probably best secured by graduating the tent, making it in effect a tape. If a loose tape is used one end may be thrown over the tent or the tape may be put in position by the use of a light fishpole, as described in Bulletin No. 152 (fig. 2). In this case the distance over is first taken by going half way around the tent and the line then lowered by the use of the pole and the circumference determined after going the remainder of the way round. This and the use of marked tents are undoubtedly the most rapid of all direct measurements, and the latter the most practical method for field work where extreme accuracy is required. As will be explained below, judgment must be used in measuring trees or the results may be very far from accurate.

Optical methods.—The different size of trees is so evident to the eye that it is not strange that fumigators have been convinced that their judgment was sufficiently accurate to replace the slow and difficult methods heretofore available for measuring trees. All optical methods of measurement, like surveying, are based upon the comparison of similar triangles (ABC and ADE, fig. 3), and depend upon the fact that the sides of similar triangles are exactly proportional to each other, thus in figure 3, if the line AB, BC, and AD are all known one can calculate the length of DE. Four methods have occurred to us as available for optical measurement and more or less completely tested out. These consist in applying the principle of the

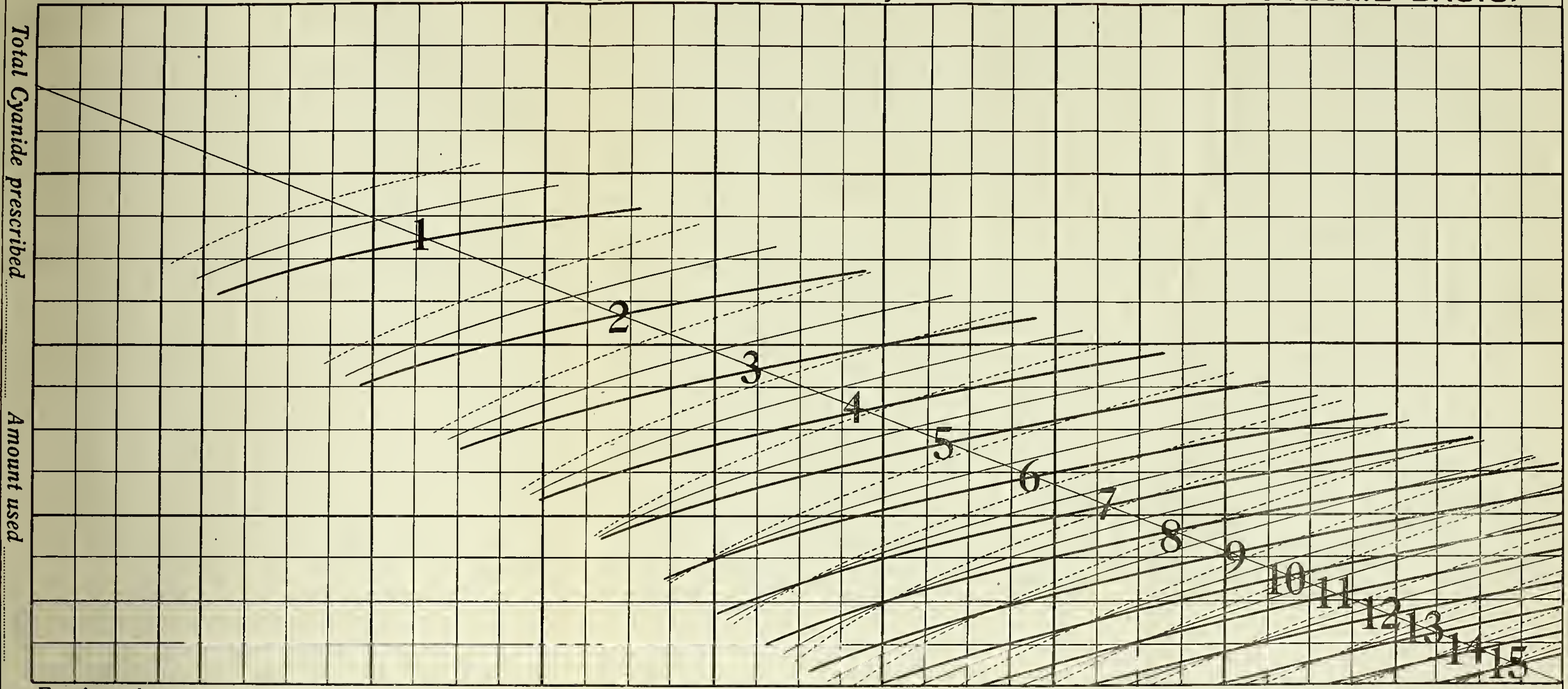
Scheduled .... *191* ..... *by* ....

FUMIGATOR'S SCHEDULING CHART.

DESIGNED BY C. W. WOODWORTH.

Dose for 10 foot tree .... *ounces. Agricultural Experiment Station—University of California.*

VOLUME BASIS.



Fumigated .... *191* ..... *by* .... *Location of Plot* ....

minations accurate to a small fraction of an ounce.

Note (*a*).—Some fumigators increase or decrease the dose a half ounce or more for badly infested trees, for especially dense trees, or for irregularly shaped trees. Where this is done it may be indicated on the chart by placing a dot in a corner of the appropriate square. If the dose is increased, put the dot in an upper corner; if reduced, below; and if on account of the character of the tree place the dot to the left; if because of the abundance of the scale place it in one of the right-hand corners.

Note (*b*).—Three charts are issued: one on the basis of volume, one on the basis of area, and the third on the basis of linear dimensions. On the Volume and Area Basis charts feeble curved lines indicate intermediate calculations. The two charts provide therefore for any of the following plans of scheduling:

$$\left.\begin{array}{l}\text{1. Volume basis}\\ \text{2. } 4/5 \text{ Volume basis } (1/5 \text{ area})\\ \text{3. } 3/5 \text{ Volume basis } (2/5 \text{ area})\end{array}\right\}\text{ on Volume basis chart.}$$

$$\left.\begin{array}{l}\text{4. } 3/5 \text{ Area basis } (2/5 \text{ volume})\\ \text{5. } 4/5 \text{ Area basis } (1/5 \text{ volume})\\ \text{6. Area basis}\end{array}\right\}\text{ on Area basis chart}$$

With very leaky tents, like those most commonly employed, a strong dose and an area basis or 4/5 Area basis is suggested. Tighter tents probably should come nearer a volume basis.

(1) photo camera, (2) the magic lantern, (3) displacement mirrors, and (4) direct vision.

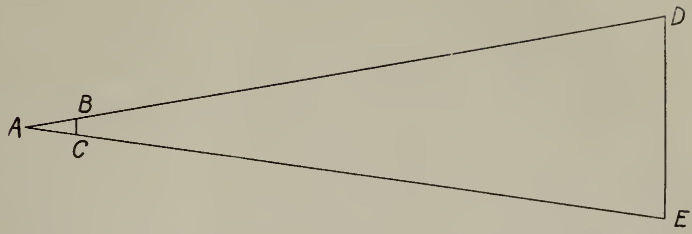


Fig. 3.—Optical measurement depends on the fact that $\frac{AB}{BC}=\frac{AD}{DE}$.

The *photo camera* method was first proposed by Mr. W. B. Parker, a student and assistant in the Department, and largely worked out and tested by him. The idea was to examine the tree on the ground glass from a definite distance, either determined by the position of adjacent trees or by the sharpness of the image, and to dose the tree according to a diagram drawn on the ground glass. Referring again to figure 3, the lines AB and AD are thus invariable and the size of the tent determined by the length of BC in the two dimensions. It would be possible to maintain AB and BC as invariable for diameter and measure AD as described below under direct vision; indeed, the camera did not seem to present any advantage over the other method, and was therefore discarded.

The *Magic lantern* method is particularly available for night work, but has not yet been sufficiently tested. It will at best be a relatively expensive instrument. The principle is to approach the tree until the diameter of the illumined field corresponds with the width of the tree, thus maintaining the length of the line BC constant for the diameter and arrange an oblique slide in such a position that the appropriate graduation appears in focus on the tent. The ratio between the conjugate foci of the lenses is that between AB and AD — AB — $\frac{1}{2}$DE. This would appear to be the most rapid and least liable to error of all night methods, since after the instrument is once adjusted the fumigator need only see that he is in such a position that the width of the tent is in the light when bringing the top of the field to correspond with the top of the tent the figure appearing clearly in focus on the tent nearest the ground gives the proper dose in ounces. Since a fumigator carries a lantern anyway the method requires no extra apparatus.

Displacement mirrors are used on instruments requiring great precision, such as sextants and may prove the most accurate of the

optical methods. The apparatus will be somewhat expensive, but will be tested out more fully in the near future.

The *direct vision* methods, because of the cheapness and simplicity of the apparatus required, will without doubt be more acceptable to fumigators than either of the methods mentioned above. They are available for either day or night scheduling, though more satisfactory for day work. These methods fall into two classes: first, those in which the line BC is constant for diameter and AD variable; and second, those having AD constant and BC variable for both dimensions. The former is the more accurate and the latter allows greater rapidity in scheduling, but both are very much more rapid than any direct measuring method and may be read accurately to within half an ounce for small and medium sized trees, an accuracy as close as is needed in practical fumigation. A third form in which AB was the variable was tried, but the difficulty of calculation was not readily overcome, so this plan was discarded for the other two.*

We shall now proceed to discuss in detail the two preferred forms of apparatus for optical measurement by direct vision.

THE "ACCURATE" METHOD.

The practical difficulty that had to be overcome in the development of an optical method was the establishment of what surveyors call a base line, that is, an accurately measured reference line. Referring again to the diagram figure 3, the adjustment of the instrument provides for the proper proportioning of the lines AB and BC. Now if we accurately measure the base line AD we will have the size of DE with the same accuracy. In the "rapid" method described below the length of AB is only approximately determined by the way the orchard is laid out, but for greater accuracy this distance must be actually measured.

Since it is difficult to place the end of the tape in the center of the tree it is entirely practical to measure not the whole distance AB, but only that from the eye to the nearest point on the tree giving AD — $\frac{1}{2}$DE, from which it will be quite as easy to calculate the dimensions.

The apparatus consists of a sighting diagram and a specially graduated tape reading in ounces. A different diagram will be required for each different basis of calculation, as will be explained below.

* Mr. C. E. McFadden of Fullerton, to whom fumigators are indebted for great improvements in handling large tents and who has also been working for some time to develop methods of optically measuring tents, tells me that he has nearly perfetced an apparatus working on this principle.

The process of measuring a tree when done by one person consists in attaching one end of the tape to the nearest point on a tree or tent, then backing off until the width of the tree just fills the diagram. If the top of the tree also corresponds, the graduation on the tape indicates the ounces that should be used. A series of marks on the diagram indicates the amount to add or subtract for high or low trees.

Fig. 4.—Measuring the tree by the use of a tape, the "accurate" method.

If instead of attaching the tape to the tree the end is held in place by a boy more rapid work will be done. In this case the scheduler will hold, in his left hand, the scheduling board to which the sighting diagram is attached and allow the tape to slip between the fingers of the same hand. With the right hand he holds his pencil and adjusts the tape. The procedure is as follows: The scheduler walks towards the tree to be measured, slacking his pace as the tree about fills the diagram, while the boy continues until he reaches the tree, thus pulling the tape into the proper position. The fumigator in the meantime has determined the height of the tree, and as soon as his helper announces having reached the tree both start to the next position, the scheduler, having noted the graduation of the tape, pulled it back ready for the adjustment for the next tree, added or subtracted the half ounce or more if the tree

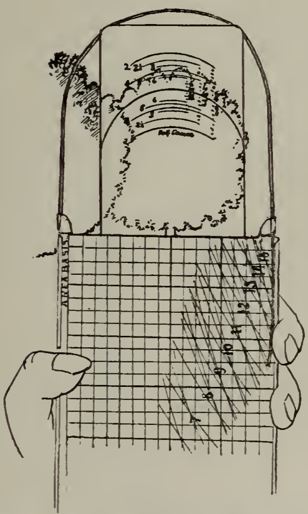


Fig. 5.—Tree as seen through the diagram. For such a tree add one-half ounce if the tape reads 4, 5, or 6 ounces.

proved high or low and set down the proper dosage on the schedule sheet. All this is done in much less time than it takes to describe the process. Two rows may be taken at once, the helper moving across from side to side, going first to the larger and then to the smaller of each pair of trees. By following this method the scheduler may proceed down between the rows scarcely stopping as he measures the trees.

The most convenient means of holding the chart at a constant

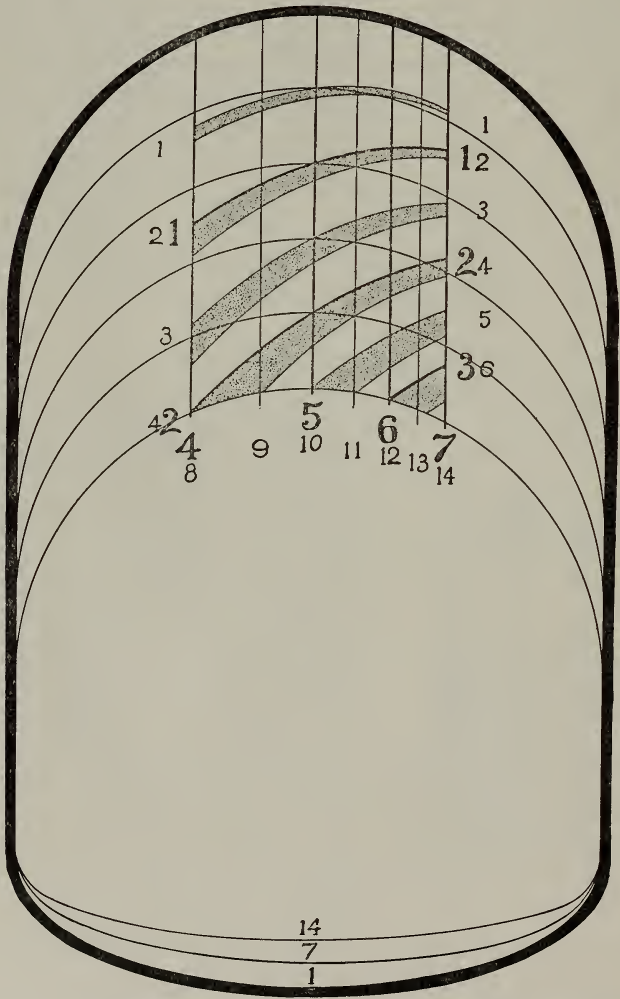


Fig. 6.—Scheduling diagram in which tape reading is diminished for shorter trees.

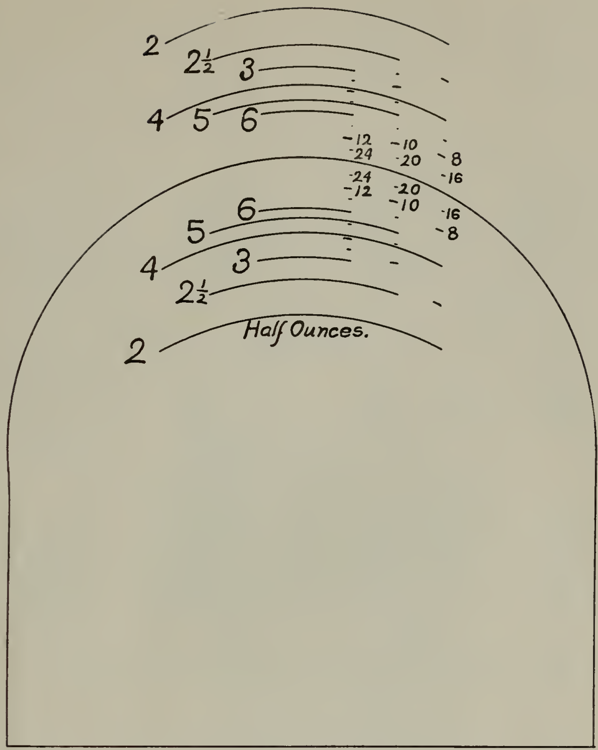


Fig. 7.—Diagram in which tape reading is raised or lowered for high or low trees.

distance from the eye is by the use of a light wire around the hatband. The end of the wire is bent into a hook, against which the chart rests when making an observation. The method of determining the point at which to bend the wire is described below.

THE "RAPID" METHOD.

For practical work the base line can be determined accurately enough by the scheduler locating himself by the way the orchard is laid out, and one man can schedule four rows at a time almost or quite as rapidly as by guess.

The apparatus consists of an arrangement for holding a loop of steel wire* at a constant distance from the face which can be so bent as to conform with the shape of the tree, being adjustable both for height and width.

In order to obtain uniform readings with this instrument it is

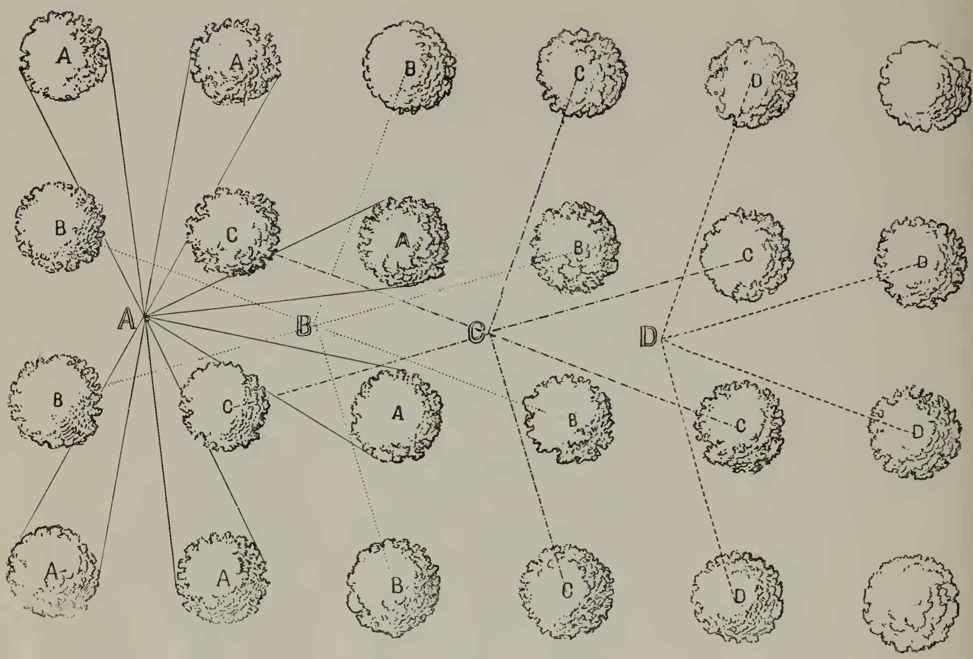


Fig. 8.—Positions to stand in scheduling an orchard.

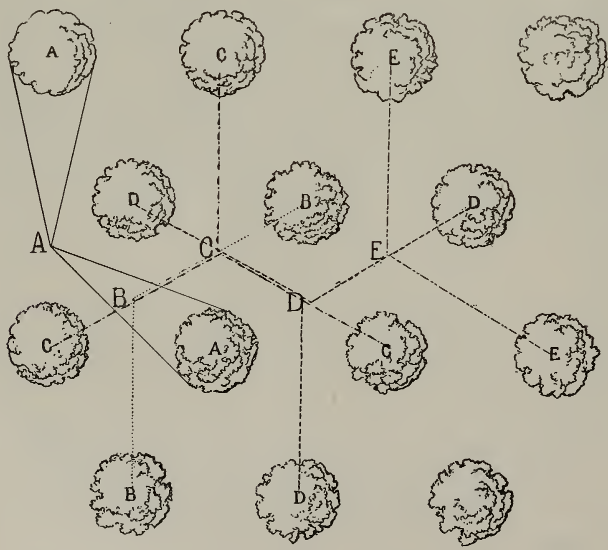


Fig. 9.—Scheduling an orchard planted in diagonal rows.

necessary to hold the chart at a constant distance from the eye as with the "accurate" method, and one must also stand at a uniform distance from the tree to be measured. The best position for this purpose is the middle point between the rows.

The immediately adjacent trees are too close to accurately measure, but the next trees are usually well in view or will become so by taking a side step in such a direction that the distance to the tree in question is not changed. In the case of a very large tree it may be necessary to approach till just between two adjacent trees, so as to bring the whole tree in view. The distance AB must be varied in adjusting the instrument according to the position at which one will have to stand in scheduling the orchard.

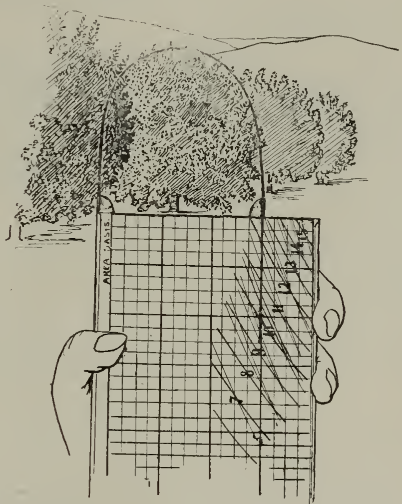


Fig. 10.—Appearance of tree through the loop.

THE CALCULATION.

After the dimensions of a tree are obtained by any method of measurement we have still the determining of the proper dose corresponding with the size. This is too complicated a matter to undertake in the field, so that all practical methods of measurement must be combined with a rapid means of accurate calculation, and no method that does not provide for variations in calculation will be acceptable.

* I desire to acknowledge the suggestion of the use of a steel tape made to me by Mr. McFadden. My apparatus had been based on rigid bars measuring height and diameter. The tape which measures the distance over instead of height makes the apparatus somewhat simpler in construction and is fully as accurate.

The method of marking tents illustrated in Bulletin No. 152 has this fatal defect, because as soon as measurement becomes the regular practice the significance of variations which many fumigators regularly make in scheduling tents can be tested out and their value accurately determined and incorporated in the system of scheduling. In the direct measurement of tents the calculation may be made beforehand and presented in tabular form, in which case a series of tables

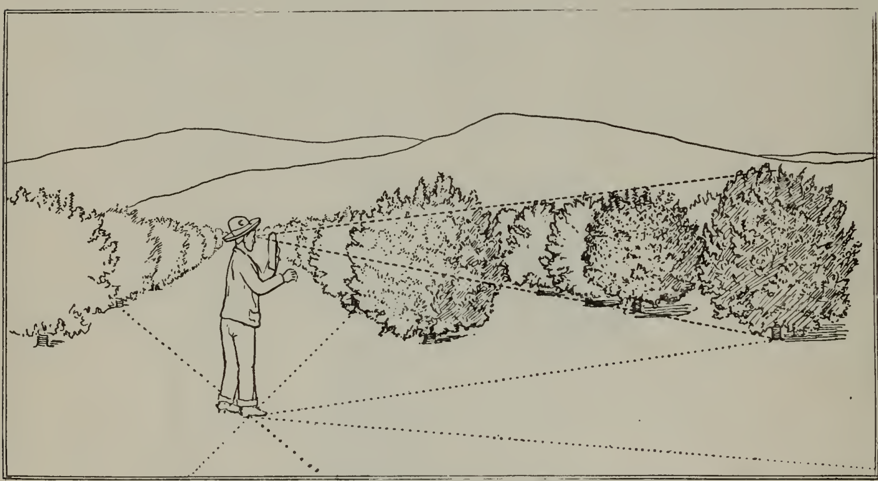


Fig. 11.—Scheduling trees by the rapid method.

must be used to accord with the different strength of cyanide desired or the different basis of calculation. The charts described below afford a new and improved means of obtaining the dose.

In the two new methods of measurement here described difference in dosage is provided for in the adjustments of the instruments and difference in basis of calculation by using different tapes or charts. No one has heretofore pointed out the fact that two entirely different factors enter into the determination of the amount of cyanide to use. For instance, fumigators were found to vary all the way from 2 to 7½ ounces for a 10-foot navel orange having the two dimensions approximately equal. This we may call a difference of dose, but two fumigators having the same dose, say 5 ounces, for a 10-foot tree may nevertheless vary from 7 to 32 ounces in their judgment of the proper dose for a 20-foot tree. Such differences represent different methods of calculating the rate of increase of dose to correspond with increase of size. This we will call difference of basis of calculation.

THE DOSE.

The original determination of the dose in cyanide fumigation was for a 12-foot tree, as made by Mr. Morse of this Station (Bulletin No. 71) for the killing of the cottony cushion scale, amounted to 8 ounces of cyanide. Mr. Coquillett about the same time (Report U. S. Dept. of Agr., 1885) experimented with 10-foot trees, and his determination was 4.6 ounces of cyanide.

Subsequently many tables have been published, in most of which one can only guess which items represent actual determinations of killing strength and which are determined mathematically.

In Bulletin No. 152 (page 7) the dose actually given by twenty-three fumigators to the same sized tree (about 8 feet) was tabulated, and showed a range from 1 to 7½ ounces, with an average for San Bernardino, Los Angeles, and Orange counties of 3.2, 3.6, and 4.8, respectively, the latter largely based upon purple scale, which probably requires about that ratio of increase over the dose for black scale. The latest determination is that made by Woglum for purple scale of 11½ ounces for a tree 10.36 feet high by 12.73 in diameter, corresponding about with a 11½-foot tree of equal dimension.

In order to compare these systems it will be necessary to reduce them to a uniform size of tent, and while perhaps not exactly fair the best method for such reduction is to adopt the method calculation used by each. This gives for a 10-foot tree:

For cottony cushion scale	Morse	4.5 oz.
	Coquillett	4.6 oz.
For black scale	Average practice	4 oz.
For purple scale	Average practice	6 oz.
	Woglum's table	7½ oz.

The largest recommendation I find is that of Pease, for red scale, of 8 ounces, though the red usually receives a dose intermediate between that for the black and the purple scale.

THE BASIS OF CALCULATION.

When Morse published the original table for the dosage of trees he assumed that the correct basis of calculation was the cubic contents of the tents and prepared his table on that basis, giving 1 ounce of cyanide to each 145 cubic feet. All of the early writers about fumigation agreed with Morse in the method of calculation, only suggesting changes in the strength of the dose. Practical fumigators, however, soon began to deviate from the published tables by weakening the

dose of the larger trees and strengthening that of the smaller ones, and that has become now the universal practice of California fumigators, though they differ widely among themselves as to the amount of variation from a volume basis.

The first table published recognizing this tendency is that of Craw in 1891. The first part of his table is obtained by multiplying the height by the breadth and dividing by 24, and the latter part shows a further weakening of the dose, probably to approximate what he found to be actual practice. This table has been the basis of several others, none mathematically consistent, but apparently more nearly justified by experience than any table calculated by the Morse basis of volume.

The only suggestion hitherto made towards a method of calculation corresponding with the experience of fumigators was in Bulletin No. 152. This suggestion was a tentative recommendation that since the tents now in use leak gas very freely it might be justifiable to disregard volume entirely and dose the trees in accordance with amount of tent surface; that is, in proportion to the leakage area, and a table was presented showing this system as applied to tents marked to indicate the dosage. Since the publication of this suggestion at least three writers have adopted it. One of whom, Mr. Woglum, has experimented in California.

It is very evident that leakage is a prime factor in determining the relative amounts of cyanide to use in tents of different size, but there may be other important factors, such as absorption of gas by the plant, and even for leakage the area basis of calculation is only an approximation and not mathematically correct, as supposed by those who have adopted it.

The Experiment Station proposes to investigate at once the factors concerned in the basis of calculation and may later be in a position to make definite recommendations, and in the meantime will have to be content in presenting a statement of the actual practice of fumigators and furnish means of calculating according to whatever basis a fumigator may desire to adopt.

No one at the present time follows strictly the Morse or volume basis of calculation. This fact is perhaps largely because no one uses the tight tents such as were in vogue during the early days of fumigation. According to this system, a 20-foot tree would require eight times the dose of a 10-foot tree. It may be that if tight tents are again resorted to we may return to a volume basis of calculation.

The Area basis in which a 20-foot tree receives four times the dose

of a 10-foot tree was suggested by this Station in 1903, and is that advocated by Mr. Woglum. This amount is exceeded by some of our fumigators and may be too low when tents tighter than the average are employed, but is probably as safe a basis to adopt as any until our knowledge of the matter is a little more advanced.

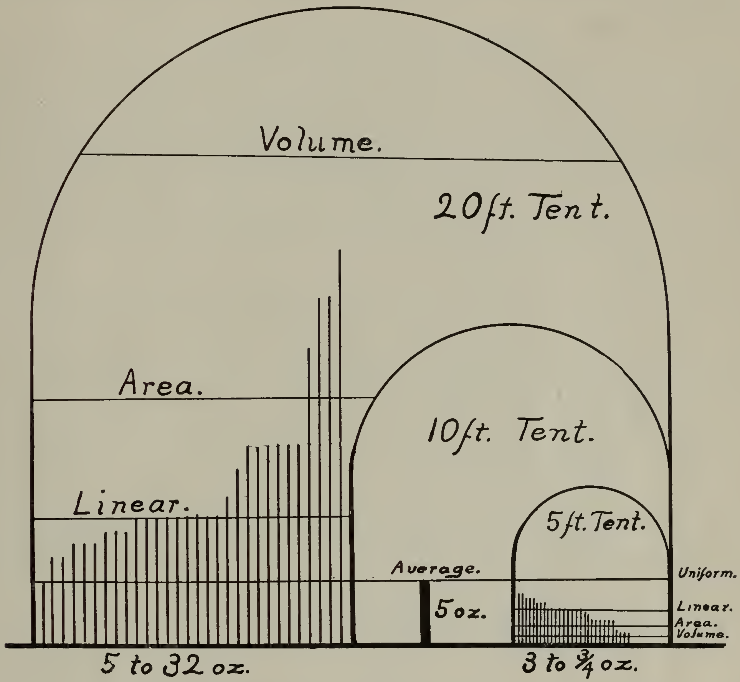


Fig. 12.—Diagram showing the actual practice of thirty fumigators in the calculation of large and small trees.

The Linear basis in which the 20-foot tree receives twice as much as the 10-foot tree is certainly nearer the practice of a majority of our fumigators than any other basis of calculation, but whether they are justified in this remains to be determined. I know of no theoretical reasons justifying this basis of calculation, but can not condemn it with our present inadequate understanding of the facts upon which a correct calculation must depend.

A very few fumigators have adopted a uniform basis of dosage, but only for orchards in which the trees do not present excessive variation. There is, of course, no justification in this practice from the standpoint of efficiency of the fumigation, but the practical convenience of method in the field may compensate for the lack of econ-

omy. The dose must be made large enough for the largest trees and is larger than need be for all others.

Figure 12 shows the actual practice of thirty fumigators by which one can see at a glance by the relative height of the vertical lines how the judgment of our fumigators stand as to the proper basis of calculation.

METHODS OF CALCULATION.

It will be desirable to provide means of calculating on a volume an area and a linear basis for each of the three methods of measuring here described. The formulae for these three bases of calculation are:

Volume $v = \pi r^2 \left(h - \frac{r}{3}\right).$

Area $a = 2\pi\, rh.$

Linear $l = r + \frac{h}{2}.$

The measurements actually made are:

Diameter $d = 2r.$

Circumference $c = 2\pi r.$

Distance over $o = \frac{c}{2} + 2h - 2r = 2h + (\pi - 2)\, r.$

and the values of r and h are:

Radius $r = \frac{d}{2}. \quad = \frac{c}{2\pi}.$

Height $h = \frac{o}{2} + \frac{c}{2}\left(\frac{1}{\pi} - \frac{1}{2}\right).$

In calculating the tables for direct measurement the most convenient formulae are:

$$v = \frac{c^3}{12\pi^2} + \frac{c^2}{16\pi}\,(2o - c).$$

$$a = \frac{c^2}{\pi} + \frac{c}{2}\,(2o - c).$$

$$l = \frac{c}{\pi} + 2o - c.$$

which are so calculated that when $2o = c$ the last term becomes zero. This is the shape of the shortest and broadest trees; with higher trees o being greater than half of c the last term gives the corresponding increment.

For the optical methods an average navel orange tree is a more satisfactory standard shape in which $2r = h$ or $h = d$, and $h - d = o - d\frac{1+\pi}{2}$, the formulae are:

$$v = \frac{5\pi}{24}d^3 + \frac{\pi d^2}{4}(h - d).$$

$$a = \pi d^2 + \pi d\,(h - d).$$

$$l = d + \frac{1}{2}(h - d).$$

in which, as before, the last term is zero with the standard shape and gives the increment when the dimensions vary.

The following constants will be found useful for actual calculations:

$$\pi = 3.1416,\ 16\pi = 50.2656,\ \pi^2 = 9.8696,\ 12\pi^2 = 118.4352,\ \frac{1}{\pi} = .3183,$$

$$\frac{\pi}{2} = 1.5708,\ \frac{\pi}{4} = .7854,\ \frac{5\pi}{24} = .6545,\ \frac{1+\pi}{2} = 2.0708,\ \frac{1}{12\pi^2} = .00844,$$

$$\frac{1}{16\pi} = .019894,\ \sqrt{\frac{1}{\pi}} = .17724,\ \sqrt[3]{12\pi^2} = 4.9109,\ \sqrt[3]{\frac{24}{5\pi}} = 1.15186.$$

The method of using these formulae and constants will be seen from the following example: Calculating on the area basis, if $c = 20$, $c^2 = 400$, $400 \times .31831 = 127.324$ square feet when $o = \frac{1}{2}c$ or 10 feet. If $o = 12$ feet, then $10 \times (24 - 20) = 40$, $127.324 + 40 = 167.324$ square feet, and every 2 feet in value of o adds 40 square feet to the surface of the tent.

GRAPHIC CALCULATION.

The calculation of tents can be made very rapidly and accurately by employing a graphic method instead of figuring out each case by the use of the above formulae. Such a diagram was illustrated in Bulletin No. 152 for volume calculations, but the method of its construction was not described. One of the optical methods of measuring here recommended involves the practical use of such a diagram, so the construction of these diagrams will be described below.

The dimensions chosen for the width of this diagram were 5¾ inches and a loop of steel wire was taken of such length that when the ends were placed at the distance apart of 5¾ inches and so held as to correspond with the normal shape of a tent the height was also 5¾ inches.

The length of this tape amounts to 14¾ inches, as calculated from the formula for *o* previously given. Lay off, therefore, 14¾ inches along the top of the chart and draw a diagonal. Obviously when one end of the tape is fastened to the upper angle of the chart and the other brought to any point on this diagonal line, provided the ends lay parallel with the upper edge of the chart, the projecting loop will have the height and width equal, and the second set of formulae given above will apply. An inspection of these formulae will show that the dose varies according to its cube root in the case of volume basis, according to its square root for area and directly for linear calculations. In the three charts here presented the dose of 16 ounces is chosen to correspond with the maximum size of the loop and the doses 1-15 are laid off on the diagonal line in the ratio of the roots of these numbers. Each dose will correspond with a curve which intersects the diagonal line at the points just laid off. Other points on these curves can be obtained by drawing other oblique lines and computing the relative position of any particular dose and, then, with the use of two triangles, lay off the other doses in the same proportion as they occur on the diagonal line. Two or three oblique lines on either side of the diagonal will enable one to locate all the curves in a very satisfactory manner.

USE OF CHART FOR CALCULATING DIRECT MEASUREMENTS.

One may use this diagram for calculating the dosage from direct measurements. If the measurements are taken in terms of *h* and *d,* one lays off along the diagonal line equal spaces corresponding to the dimensions; now lay a card on the chart, keeping it square with the edges of the chart, and make it cross the diagonal line at the two dimensions and the corner of the card will indicate the dose. If the height is the larger, read above the diagonal; if smaller, read below. (See fig. 13.)

When the dimensions are in terms of *c* and *o,* draw another oblique line along the upper ends of the curves and graduate it as before, determining the dose by the use of a card in the same manner from the graduations of this line.

The accurate graduation of the oblique lines is not a difficult operation. The methods are as follows:

FOR HEIGHTS AND BREADTH.

Graduate the diagonal line, for measurements in terms of *h* and *d*:

First, lay a ruler along the top of the chart as shown in fig. 13, bringing 14¾ inches at the upper right-hand corner of the chart.

Second, connect the 10-inch division with the dose desired as indicated along the diagonal line, say 6 ounces, as shown in the figure.

Third, draw parallel lines from the ruler to the diagonal line from each inch division. In this way graduate the whole length of the diagonal line. Each division so marked will correspond with a foot in height or width of tree.

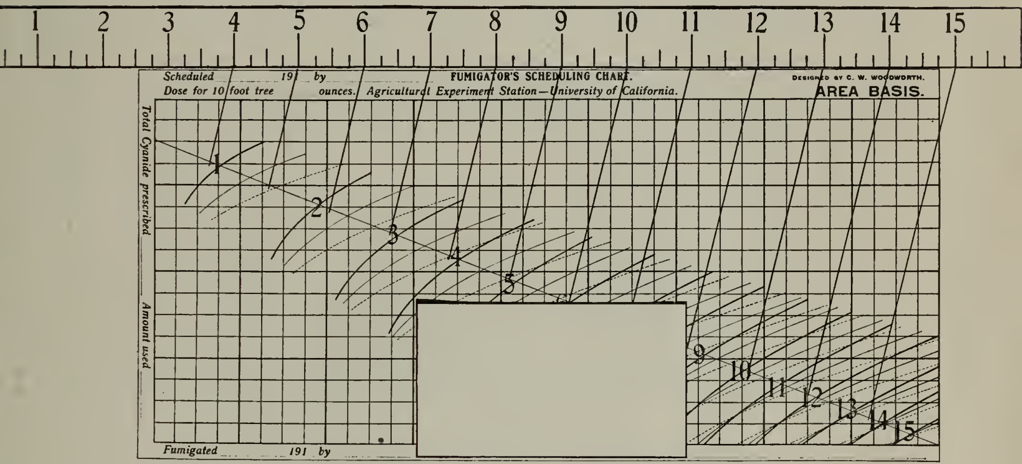


Fig. 13.—Method of graduating the diagonal line for a 6-ounce dose for a 10-foot tree, and the use of a card showing that on this dose and basis a tent 12 feet high and 10 feet across corresponds with 7½ ounces.

FOR DISTANCE OVER AND AROUND TENT.

Graduate an oblique line to be drawn along the upper ends of the curves for values in *c* and *o*:

First, place a card on the chart with the corner at the dose desired for the 10-foot tree (fig. 14, showing 4 ounces), keeping the cord square with the edges of the chart and marking the points of intersection with the oblique line. The dimensions of a standard shaped tent are 20.7 feet and 31.4 feet, respectively; therefore, mark these points on the oblique line and also mark on the card the points where the oblique line touches the edge of the card.

Second, draw a line from one of the points marked on the card and mark along it ten equal distances and make a division at the end seven-tenths as long as the others. Now draw a line from the end of this short division to the other mark on the card and a series of parallel

lines through the graduations, as shown in figure 15. These parallel lines intersect a line connecting the two marks first made on the card, each giving the correct distance to correspond with a foot on the oblique line.

Third, the short division will locate the 20-foot point and then the whole line may be graduated in feet. It will thus take but a few minutes to graduate a chart to correspond to any dosage desired and the dose can be determined from any given dimensions with great facility and accuracy, according to any desired system of scheduling, and avoid entirely any recourse to mathematical calculation.

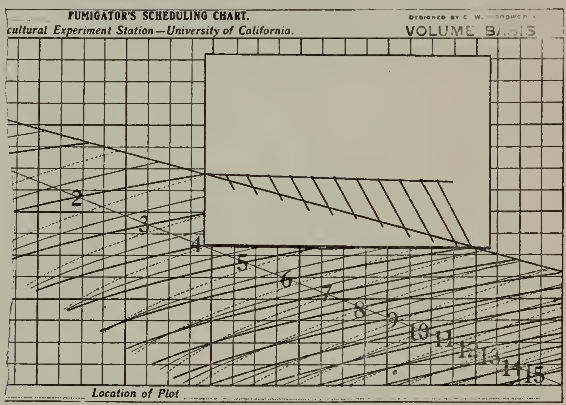


Fig. 14.—Method of graduating the line used in calculating from tent measurements.

USE OF CHART FOR GRADUATING TAPES.

The graduation of the tapes for the "accurate" optical method of measurement may be done either by mathematical calculation or by the use of the charts. The exact length of the tape is only a matter of convenience, since the adjustment of the distance the apparatus is held from the eye can be varied through rather a wide range. It is only necessary that the graduations be correctly placed as regards each other. As has already been shown, these relationships are the roots of the numbers, just the quantities that have been used in constructing the charts.

To graduate the tapes mathematically one would multiply successively the roots of 1, 2, 3, etc., by such a constant that the highest number would give a convenient length of tape and lay off each of the products on the tape.

Scheduled .... 191 .... by ....

FUMIGATOR'S SCHEDULING CHART.

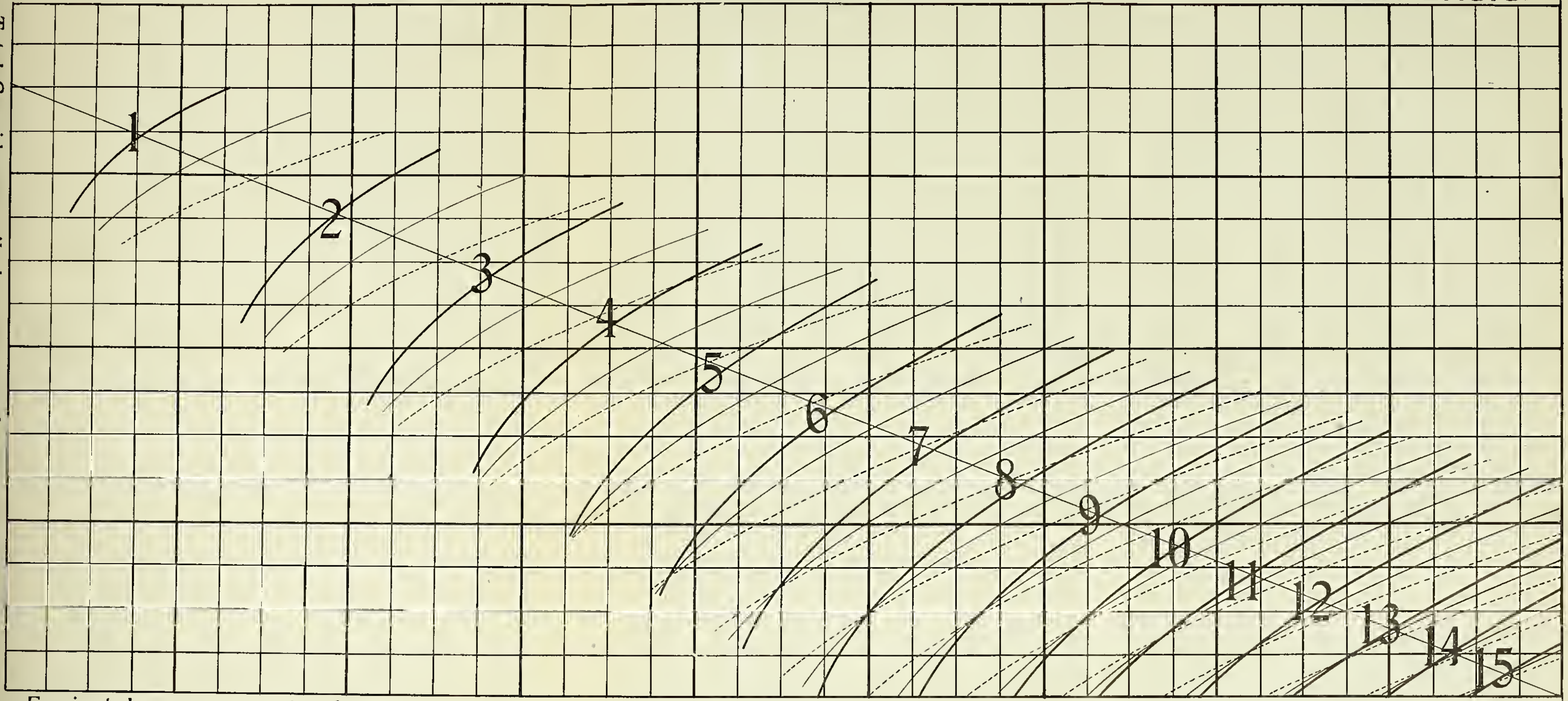
DESIGNED BY C. W. WOODWORTH.

Dose for 10 foot tree .... ounces. *Agricultural Experiment Station—University of California.*

AREA BASIS.

Total Cyanide prescribed ....

Amount used ....

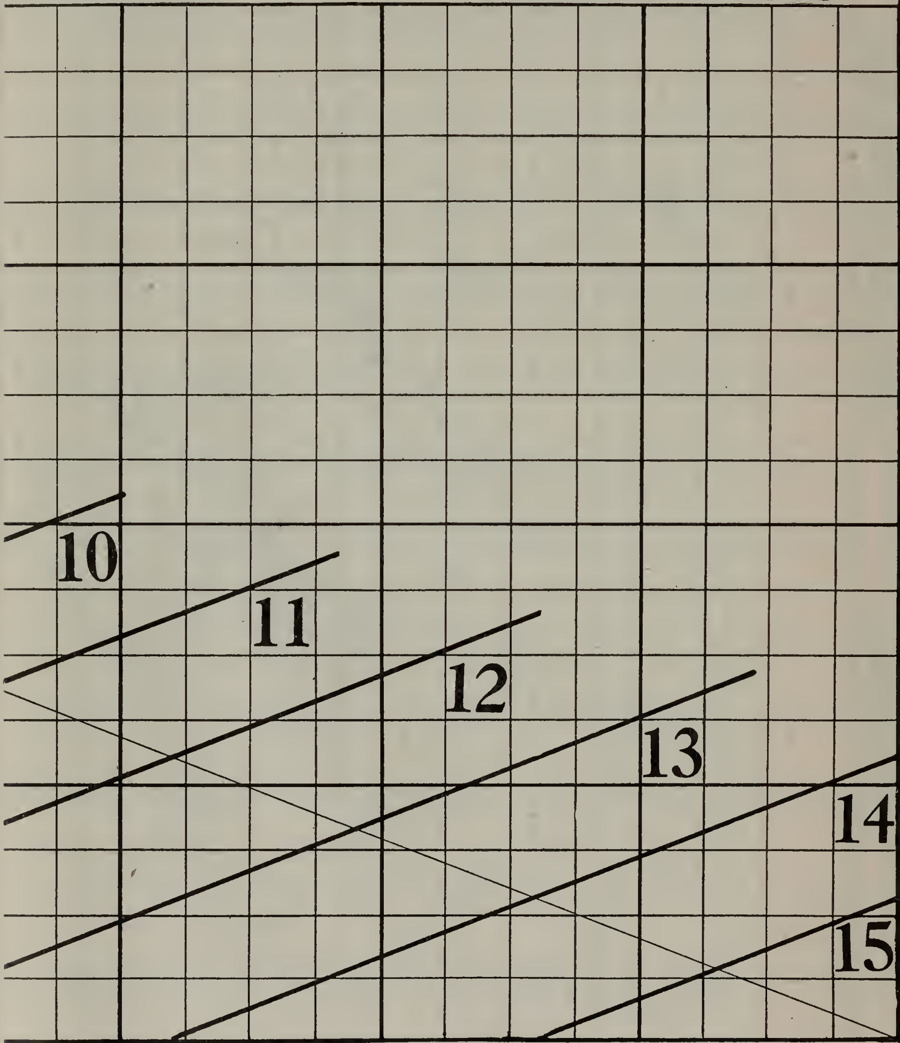


Fumigated .... 191 .... by .... Location of Plot ....

ifornia.

DESIGNED BY C. W. WOODWORTH.

LINEAR BASIS.



Instead of performing all these multiplications the same end may be secured by graduating the diagonal line in the manner previously described, but making the number of divisions such that they will conform to feet in the length of the tape and give a convenient length. Thus, perhaps, a 32-foot tape may be a convenient length and the diagonal line would then be divided into half inches. Calling every half inch a foot, the tape could be graduated according to the intersections of the curves and the diagonal line.

PRECAUTIONS AND ADJUSTMENTS.

No system of measurement or calculation can be devised that will not be more or less inaccurate in the hands of an ignorant or careless operator, and even in the hands of the most intelligent and careful scheduler there will be a certain range of error.

It is a wise plan to try to determine not only the sources of error, but also the amount of error each is liable to introduce into the final result. With this in view let us compare the three more important methods of measurements.

Errors with marked tents.—When tents are thrown over a tree the center rarely falls twice in the same relative position. A single row of marks down each side may sometimes give a reading several ounces smaller than though the line went over the highest point. This defect has been partly overcome in the marking covered by Mr. Morrill's patent, and recommended by Mr. Woglum, by using three lines with the thought that one of them would be likely to lay over the treetop. My own markings attempted to gain the same end by making the lines long. Possibly the best plan is that first suggested by Mr. Payne, referred to in Bulletin No. 152, of making the marks take the form of rings, in which case the sum of the largest and smallest distance would be over the highest point. This plan of marking is, however, also covered by a patent. Even here the dimensions may not be entirely correct if the tree is irregular in shape. With a detached measuring device one could be quite sure of getting his error on the safe side, and with any form of marked tents there is still room to exercise judgment, even to the extent at times of calling a dimension different from anything shown by the marks.

The circumference taken by stepping is another source of error of considerable magnitude, as shown by the fact that only a few people are successful in stepping in a way to correspond with tape measurements. The plan of pacing around the tent was first suggested by myself, but there is no saving of time as compared with the use of

the tape. With the tape the circumference becomes the most accurate of any measurements it is possible to make of fumigation tents.

A third source of error of no small extent is the use of incorrectly calculated tables. One such table has been extensively used in which errors occur amounting to 25 per cent., both above and below the correct dose. It should be noted that Morrill's patent covers the style of table recommended by Mr. Woglum.

ADJUSTMENTS AND ERRORS IN THE "ACCURATE" METHOD.

Both optical methods require a preliminary adjustment of the wire about the hatband so as to hold the diagram a constant distance from the eye. This is not difficult to do, and the amount of the error introduced by faulty adjustment can be seen in terms of the dose.

The adjustment is quickly made by having some one hold a 10-foot pole in one hand and the end of the tape in the other, so that the end of the tape is 5 feet from the pole. Now taking such a position that the number of ounces corresponding with the 10-foot tree is indicated on the tape at the distance of the eye when the tape is held straight, move the diagram until the length of the pole corresponds with the width of the diagram, then bend the wire to maintain this width.

The chief chances of error are (1) a shifting of the position of the hat making the distance of the eye to the diagram different; (2) failure to properly judge the location of the edge of the tree; (3) irregular trees. The first should be entirely avoided, the second is not very liable to make a large error, and the third can be avoided by making several readings and averaging the results when the tree is not of the usual shape.

The facility of re-scheduling trees is a particularly valuable feature of both optical methods, because the scheduler can check himself up or be checked up by others. Where tents have to be placed on a tree before it can be measured a scheduler can be morally certain that his mistakes will not be found out.

Added to these sources of error is the question of the effect of the weight of the tent in reducing the size of a tree. Errors are most likely to be made on the safe side. The only way for a scheduler to develop his judgment in this matter is by doing more or less night scheduling and comparing it tree by tree with day scheduling.

ADJUSTMENTS AND PRECAUTIONS IN THE "RAPID" METHOD.

To adjust the apparatus, set the end of the pointer on the dose that should be given to a 10-foot tree on the diagonal line. Place a 10-foot pole at the distance one will stand in scheduling the trees in the orchard, then moving the apparatus toward or away from the face as may be necessary in order to make the width of the loop correspond with the length of the 10-foot pole; then bend the end of the wire to support the loop precisely that distance from the eye.

The most important source of error is the location of oneself the proper distance from the tree to be scheduled. By looking between the rows in both directions one can come close enough for practical purposes and can determine quite readily the limit of error by moving the head forward and backward till clearly beyond the correct location and seeing the difference in dose indicated.

Added to this are most of the sources of error enumerated when discussing the "accurate" method. The only advantage the accurate method has over the "rapid" method is the accurate determination of the distance from the eye to the tree.

CONCLUDING REMARKS.

While the questions involved in scheduling trees are thus seen to be very intricate and complex, the actual practice of scheduling of trees in the field is a comparatively simple matter with our new methods and apparatus—simple enough, indeed, to be understood and performed by a child.

A brief but comprehensive presentation of the practical suggestions of the preceding pages will be found in the directions printed on the reverse of Chart I and upon all the charts as they are now issued by The Braun Corporation, 361-371 New High street, Los Angeles. This company has undertaken to supply the apparatus herein described at a nominal price.

RESUMÉ.

Scheduling by measure instead of guess is essential to progress in fumigation.

Older methods of measuring are not practical.

The method of marked tents devised by this Station is the most practical means heretofore suggested.

Optical methods of measuring are practical and much more rapid.

Numerous forms of optical measurement have been tested, but direct vision methods seem most satisfactory.

Two methods are recommended, one more accurate for experimental work and the other very rapid for practical fumigation.

The "Accurate" method depends on the use of a tape to measure the distance from the tree to the scheduler.

The "Rapid" method employs a loop of steel wire, the end of which points to the dose on a chart as soon as the loop is made to correspond with the size of the tree.

The calculation of the dose is a very complicated matter, and practice differs widely both as to the amount to use for a given size of tree and also the rate of change for increase in size.

A ten-foot navel orange is suggested as a standard for stating the dose and the original recommendations and actual practice is given.

The basis of calculation is at present hopelessly involved. The practice of fumigators is shown and the area basis tentatively suggested.

The formulae for calculating according to the different bases are presented in a new and very convenient form.

A graphic method of obtaining dosage is presented as a substitute for mathematics, greatly simplifying the process of calculation.

The charts presented furnish the most rapid and most adaptable method of obtaining dosage from direct measurements.

They are also the most convenient means of graduating tapes for the "accurate" optical method of measuring.

The sources of error in direct measuring are the shifting of the tent, the irregularity of the tree, pacing, and inaccurate dosage tables.

Accuracy by the optical method requires careful adjustment, that the adjustment be not disturbed, and that irregular trees be re-scheduled.

Re-scheduling affords the best possible means of improving the judgment in scheduling.

Scheduling by the new methods is very easily understood and performed as well as being rapid and accurate.